EXCERPT FROM THE

PROCEEDINGS

OF THE

FIFTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

DYNAMIC COST RISK ASSESSMENT FOR CONTROLLING THE COST OF NAVAL VESSELS

Published: 23 April 2008

by

Dr. Edouard Kujawski and Dr. Diana Angelis

**5th Annual Acquisition Research Symposium
of the Naval Postgraduate School:**

**Acquisition Research:
Creating Synergy for Informed Change**

May 14-15, 2008

	Form Approved OMB No. 0704-0188
Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **23 APR 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**
4. TITLE AND SUBTITLE **Synamic Cost Risk Assessment for Controlling the Cost of Naval Vessels**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Systems Engineering Department,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
5th Annual Acquisition Research Symposium: Creating Synergy for Informed Change, May 14-15, 2008 in Monterey, CA

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**46**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

Proceedings of the Annual Acquisition Research Program

The following article is taken as an excerpt from the proceedings of the annual Acquisition Research Program. This annual event showcases the research projects funded through the Acquisition Research Program at the Graduate School of Business and Public Policy at the Naval Postgraduate School. Featuring keynote speakers, plenary panels, multiple panel sessions, a student research poster show and social events, the Annual Acquisition Research Symposium offers a candid environment where high-ranking Department of Defense (DoD) officials, industry officials, accomplished faculty and military students are encouraged to collaborate on finding applicable solutions to the challenges facing acquisition policies and processes within the DoD today. By jointly and publicly questioning the norms of industry and academia, the resulting research benefits from myriad perspectives and collaborations which can identify better solutions and practices in acquisition, contract, financial, logistics and program management.

For further information regarding the Acquisition Research Program, electronic copies of additional research, or to learn more about becoming a sponsor, please visit our program website at:

www.acquistionresearch.org

For further information on or to register for the next Acquisition Research Symposium during the third week of May, please visit our conference website at:

www.researchsymposium.org

THIS PAGE INTENTIONALLY LEFT BLANK

Dynamic Cost Risk Assessment for Controlling the Cost of Naval Vessels

Presenter: Dr. Edouard Kujawski is an associate professor in the Systems Engineering Department at the Naval Postgraduate School. His research and teaching interests include the design and analysis of high reliability/availability systems, risk analysis, and decision theory. He received a PhD in theoretical physics from MIT, following which he spent several years in research and teaching physics. He has held lead positions at General Electric, Lockheed-Martin and the Lawrence Berkeley National Laboratory. He has contributed to the design of particle accelerators and detectors, space observatories, commercial communication systems, the Space Station, and nuclear power plants. He was a participant and contributor to the Lockheed Martin *LM21 Risk Management Best Practices* and the original *INCOSE Systems Engineering Handbook*. He is a member of the San Francisco Bay Area Chapter of INCOSE and has served on the board of directors.

Edouard Kujawski
Systems Engineering Department
Naval Postgraduate School
Monterey, California 93943

Author: Dr. Diana Angelis is an Associate Professor in the Defense Resources Management Institute at the Naval Postgraduate School in Monterey, CA. She joined the faculty in 1996. She studied accounting at the University of Florida and received a BS in Business Administration in 1977 and a BS in Electrical Engineering in 1985. She received her PhD in Industrial and Systems Engineering from the University of Florida in 1996. Her research interests include the application of activity-based costing in government organizations, cost estimating, the valuation of R&D through options theory, and business reforms in defense management. She was commissioned an officer in the United States Air Force in 1984 and served as a program engineer until 1989. She joined the USAF Reserves in 1990 and has worked in both acquisition and test & valuation with the Air Force Materiel Command. Dr. Angelis is a Certified Public Accountant and a Lieutenant Colonel in the US Air Force Reserve currently assigned to the Air Force Flight Test Center at Edwards AFB, CA.

Diana Angelis
Defense Research Management Institute
Naval Postgraduate School
Monterey, California 93943

Abstract

Naval vessels, like most large-capital projects, have a long history of cost growth. To get a handle on this problem, NAVSEA's Cost Engineering & Industrial Division, NAVSEA 05C, has introduced Probabilistic Cost Risk Analysis (PCRA) into the Department of Defense (DoD) Planning, Programmatic, Budgeting, and Execution System (PPBES). The quantification of cost in terms of cumulative probability distribution functions (CDF) or "S-curves" provides a macroscopic view of project risk. Risk curves alone do not provide adequate visibility into the individual project risk drivers; therefore, they are insufficient for planning and managing risk reduction activities (RRA). Complex projects typically involve a set of high-consequence, project-specific risks that require detailed analysis and for which risk response actions need to be developed and implemented. The analysis of specific risks and RRAs requires a microscopic view. We present a practical and mathematically sound approach using scenarios and Monte Carlo simulation within the framework of decision trees and risk curves. The approach is detailed using a realistic but simplified case of a project with three technical risks.

Introduction

Cost growth has been a major problem for the US Navy. Over the past four decades, the growth of US Navy ship costs has exceeded the rate of inflation. In the past 50 years, annual cost escalation rates for amphibious ships, surface combatants, attack submarines, and nuclear aircraft carriers have ranged from 7 to 11% (Arena, Blickstein, Younossi & Grammich, 2006). Along with real cost growth, the DoD has had significant problems with cost estimates. By and large, the DoD and the military departments have underestimated the cost of buying new weapon systems. A recent study by RAND (Arena, Leonard, Murray & Younossi, 2006) indicates that there is a systematic bias toward underestimating weapon system costs and substantial uncertainty in estimating the final cost of a weapons system.

The DoD recognizes that uncertainty is an important part of cost estimating. During a 2007 seminar with a naval aviation program official, the Assistant Secretary of the Navy for Research, Development and Acquisition, Dr. Etter (Burgess, 2007), stated:

> Program managers not only need to know a realistic cost estimate for their program, they need to know the percent probability of achieving that target. For example, a ship with a 40% chance of coming in on budget has a 60% chance of being over budget. Such a situation should prompt the project manager to seek help from the acquisition community. (p. 42)

There is an ongoing major shift in R&D and complex engineering projects from deterministic to probabilistic approaches. Probabilistic Cost Analysis (PCA) provides the proper framework for handling the many different elements of cost uncertainty, including project-specific, high-consequence risks. These risk drivers must be identified, assessed, mitigated, and controlled through formal risk management—which is an essential and critical discipline implemented in today's DoD projects. *The Risk Management Guide for DoD Acquisition* (2006) reads:

> Risk management is a continuous process that is accomplished throughout the life cycle of a system. It is an organized methodology for continuously identifying and measuring the unknowns; developing mitigation options; selecting, planning, and implementing appropriate risk mitigations; and tracking the implementation to ensure successful risk reduction. Effective risk management depends on risk management planning; early identification and analyses of risks; early implementation of corrective actions; continuous monitoring and reassessment; and communication, documentation, and coordination. (p. 3)

The DoD considers the definition, implementation and documentation of risk management essential to acquisition success. The DoD risk management process outlined in the Risk Management Guide consists of the following five activities performed on a continuous basis: Risk Identification, Risk Analysis, Risk Mitigation Planning, Risk Mitigation Implementation, and Risk Tracking.

This process is consistent with the AACE definition, which includes identifying and analyzing risk factors or drivers, mitigating the risk drivers where appropriate, estimating their impact on plans and monitoring and controlling risk during execution (Hollman, 2006). To be effective, PCA must interface with each of the risk management activities.

An emphasis on risk management supports efforts to reduce lifecycle costs of system acquisitions. An often-neglected concept in project risk management is the consideration of the entire project lifecycle. Analysis of risk over the lifecycle of a system can yield substantial benefits. Conversely, ignoring important stages of the lifecycle can lead to substantial problems in terms of risk for product development at the beginning of the lifecycle and for product upgrade or replacement at the end (Pennock & Haimes, 2001).

Many sources of cost uncertainty in naval vessel construction—such as economic/business factors (rates-wages, overhead, G&A, vendor/supplier stability, inflation indices, multi-year assumptions, etc.), learning/rate/curve assumptions, and cost-reduction initiatives—are well understood within the framework of a macroscopic perspective; these are effectively modeled with classical Probability Distribution Functions (PDF) such as the triangular, Beta, lognormal, and Weibull distributions. However, these factors constitute only a fraction of today's typical project risk drivers and, therefore, cost uncertainty.

The construction of naval vessels, like most complex engineering projects, is also susceptible to project-specific risk drivers, such as: low Technology Readiness Level (TRL); high design, manufacturing, and complexity; significant requirement changes; sizeable quantity changes; large funding uncertainty; severe acts of nature; and serious accidents.

It is tempting to assume or claim that the PDFs typically elicited for cost elements also quantify the project-specific, high-consequence risks. Sometimes cost analysts will go through the effort of identifying and discussing risk drivers, but when it comes to quantifying the risks and estimating contingency, they simply apply high/low ranges to WBS elements without thinking about how a particular risk driver affects one or more cost elements. We think it is invalid and counterproductive to do this because it leads to the loss of valuable information and visibility into these risks. Also, this approach tends to focus on cost reduction rather than risk mitigation. Hollmann (2007) notes that in best practice, risk analysis should begin with the identification of risk drivers and events. The cost impacts of the risk drivers and events are then considered specifically for each event.

The analysis of specific risks and Risk Response Actions (RRA) requires a microscopic view and is best carried out with tools such Decision Trees (DT), influence diagrams, or other discrete representations. This microscopic perspective offers many benefits. It is a powerful risk analysis method to explicitly model high-consequence risks and RRAs, and thereby provides a tool for making better decisions. It also assists subject-matter experts (SMEs) to think about credible, high-consequence events and better deal with overconfidence or optimism biases. However, the microscopic view is too cumbersome to individually analyze every risk and source of cost uncertainty. It complements and needs to be integrated within the PCA.

In this paper, we propose to develop a microscopic/macroscopic PCA as an integral entity of the DoD risk management process, as follows:

1. The cost and/or risk analyst (simply referred to as analyst below) and the SMEs jointly identify the individual risks using the standard DoD risk-identification process.

2. The analyst and the SMEs jointly screen the identified risks for further analysis and risk mitigation.

3. The analyst and SMEs jointly identify realistic RRAs for the screened risks.

4. The analyst models each risk and its RRAs using a DT.

5. The analyst works with the SMEs to quantify the value of the decisions and outcomes for each DT using discrete and continuous distributions. We favor the Direct Fractile Assessment (DFA) method for data elicitation and fitting the associated cost elements with a three-parameter Weibull distribution.

6. The analyst quantifies the DTs using Monte Carlo simulation. Risks and RRAs are then modeled in terms of risk curves. We, thereby, avoid relying on the minimum expected risk value, which is a serious shortcoming of standard decision analysis.

7. The analysis is readily performed using commercial Excel add-ins (Crystal Ball, @Risk…) or more specialized tools (DecisionPro, Analytica…).

The goal of this paper is to present a realistic and practical method for explicitly analyzing and controlling the cost impact of project risks and realistic RRAs. Projects can then dynamically determine the optimal temporal set of decision gates for a given probability of success—thereby reducing cost while increasing the probability of project success. We illustrate the method using a realistic but simplified case of a project with three technical risks. We close with some concluding remarks and recommendations for further development.

The Quantification of Multiple Project Risks

Consider a project with n credible, high-consequence risks $\{R_i\}$. Each risk, R_i, is characterized by a probability of occurrence p_i and a spectrum of possible outcomes with a PDF $L_i(x)$, where x is a random variable that represents the magnitude of the associated cost or loss. One may then think of this set of risks as a risk portfolio or repository (Kujawski & Miller, 2007) with a generalized discrete PDF $R_S(x)$ given by:

Equation 1. $$R_S(x) \equiv \left\{ \langle p_1, L_1(x) \rangle, \langle p_2, L_2(x) \rangle, \ldots, \langle p_n, L_n(x) \rangle, \left\langle 1 - \sum_{i=1}^{n} p_i, 0 \right\rangle \right\}$$

The total project cost is a random variable that consists of the sum of the m base cost elements $\{BC_i\}$ and the explicitly identified risk costs $\{RC_i\}$. Depending on the state of knowledge of the data, the base cost elements BC_i may be modeled as either point estimates or continuous PDFs. The total project cost TC is then the probabilistic sum of the *m* base cost elements and *n* risk-driver costs:

Equation 2. $$TC(x) = \sum_{i=1}^{m} BC_i(x) + \sum_{i=1}^{n} p_i L_i(x)$$

Equations 1 and 2 provide visibility into the link between the credible, high-consequence risks $\{R_i\}$ and the total project cost-risk curve. Monte Carlo simulation tools such as Crystal Ball and @Risk can also provide tornado charts that conveniently quantify the importance of the various risk drivers and their link to the overall cost risk. Projects can use this information to rationally identity risks. This is in sharp contrast with: (1) the use of point estimates that are at best ambiguous because overly confident staff provide low cost estimates, while others may inflate their cost estimates to make it easier to achieve success, (2) decision-making based on

qualitative assessments, and (3) the consideration of only S-curves, which only provide a macroscopic and somewhat "black box" view of project risk and cost uncertainty.

Modeling and Analyzing Risk Response Actions

We model and analyze each screened risk and the proposed RRAs using a generalized DT—where PDFs rather than discrete branches are associated with the chance nodes, and the outcomes are analyzed using Monte Carlo simulation (Kujawski, 2002). This provides a powerful technique for dealing with the complex situations typical of today's DoD projects. It avoids bushy trees and generates risk curves, thereby removing the reliance of decision-making based on expected value.

To illustrate the approach, consider the risk depicted in Figure 1. To be concrete, Risk #1 is associated with fabricating a complex module. The two risk response actions are: (i) Directly fabricate the module, or (ii) Build a prototype and then fabricate the module. The generalized DT follows the standard DT representation. Decision nodes and chance nodes are depicted as squares and circles, respectively. The branches that originate with decision nodes represent the available RRAs. The branches that originate with chance nodes represent the possible probabilistic outcomes. A descriptive label, a probability, and a cost distribution are associated with each branch. These probability and cost values are conditional on the RRA and may also be conditional on the outcome of other risks in case of interdependencies. We model the cost values using a three-parameter Weibull distribution fitted to the 10th, 50th, and 90th percentiles determined in accordance with the Direct Fractile Assessment (DFA) method.

In this example, we assume that the baseline cost is $1,100K. Risk is then given by the Value At Risk (VAR) relative to this value. The VAR corresponds to the events whereby production of the module exceeds $1,100K. The ordering of the decision nodes corresponds to different temporal deterministic events in the development and fabrication cycle of the module.
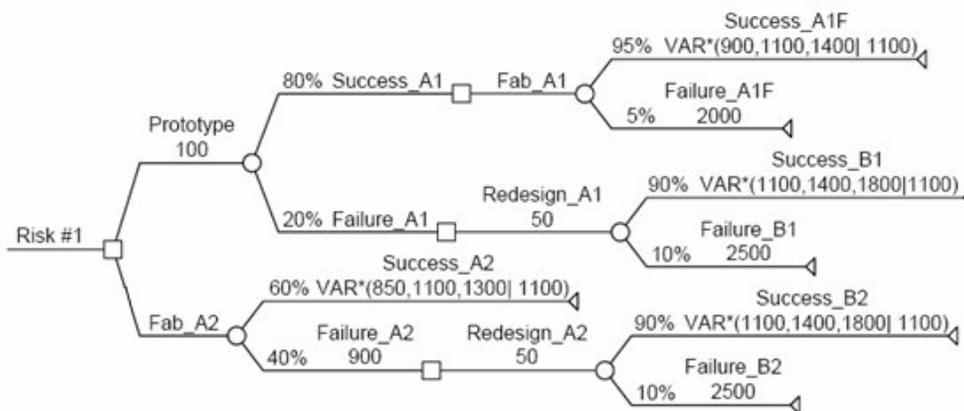
Note: In this hypothetical case, the values may be thought of as $K.

Figure 1. Generalized Decision Tree for Risk #1 and Two Initial Candidate Risk Response Actions

We evaluated each RRA in Figure 1 using the Excel Monte Carlo simulation add-in, Crystal Ball. The selection of a RRA is a deterministic event, and only the associated outcomes can be realized. It would, therefore, be inappropriate to weigh or combine the outcomes of the

two RRAs since they are mutually exclusive. The PDFs and risk profiles for each individual RRA at the start of the project are depicted in Figures 2a and 2b, respectively. The PDFs are multimodal and cannot be represented using any of the well-known probability distribution functions. The peak for the "prototype" RRA corresponds to the outcome in which the fabrication of the module fails. The PDF for the "direct fabrication" RRA has two modes corresponding to the sequence of events in which the first fabrication and the subsequent fabrication following redesign both fail.

The Complementary Cumulative Distribution Functions (CCDF) or risk curves are shown in Figure 2b, in which the exceedance probability is the probability of exceeding a given consequence or (1 − the probability of success). For example, looking at the VAR(Fab_A2) curve in Figure 2b, one reads that there is approximately a 30% probability that the cost will exceed $1,500K. Equivalently, one can state that there is a 70% probability that the cost will be less than $1,500K. The risk curve and the cumulative distribution function carry identical information content. Since we are focusing on specific risks and VAR, we favor the risk curve or CCDF because, in our opinion, it provides a better view of the residual risk and management reserve than the S-curve (or CDF) that typical represents the total cost (including the baseline and risk cost elements).

For any given value on the x-axis, the risk curve that corresponds to the lowest exceedance probability represents the lower risk. Figure 2b illustrates that the prototype risk curve is significantly lower than the fabrication risk curve and, thus, has less risk. In this hypothetical but realistic situation, the investment of $100K for building a prototype provides a significant return on the investment as measured by the significant risk reduction. To be more precise, the prototype RRA presents a lower cost of risk mitigation for all values greater than $200K. For the manager trying to decide if it is worthwhile to invest in the prototype option, the answer is to invest as long as the anticipated benefits from the prototype (whether it be cost savings, time savings, information, etc.) exceed $200K.
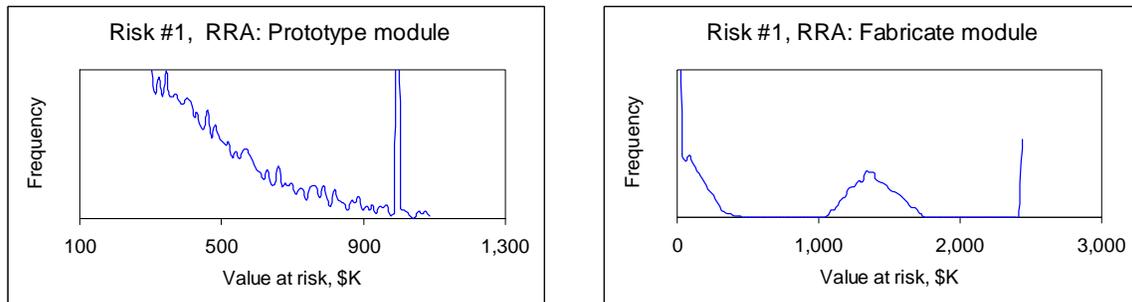
Note: Given the different scales, the two PDFs are shown separately for greater visibility.

Figure 2a. Probability Distributions Corresponding to the Two RRA Options for Risk #1
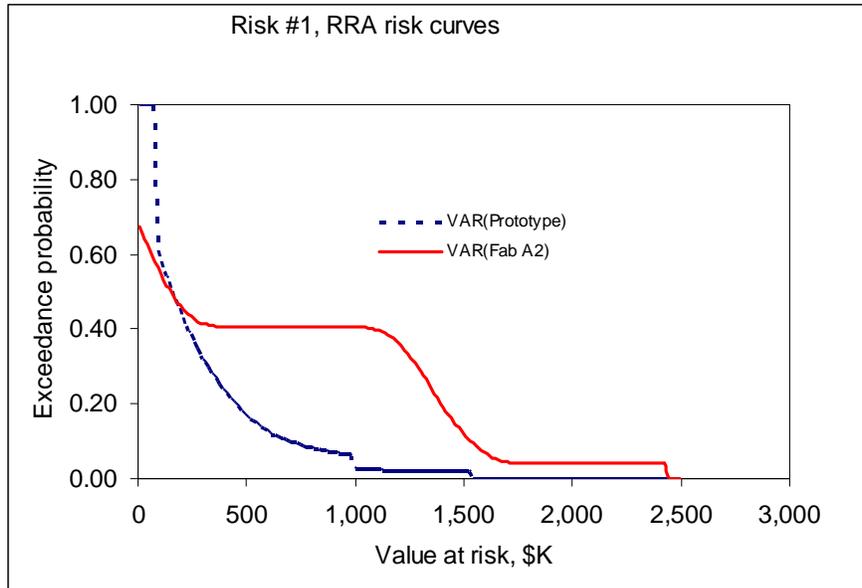
Figure 2b. Risk Curves for the Two RRA Options for Risk #1

The Dynamic Character of Risk Response Actions

As a project progresses, its risk picture is dynamic. The sources and consequences of risks continue to evolve and change over time. As more information is obtained about a particular risk, the RRA options might change; thus, it is necessary to constantly monitor risk. In general, at any point in time there will be a mix of acceptable and unacceptable results. The performance of the RRAs should be monitored and controlled to ensure they are adequately mitigating risk. Concurrently, management reserves should be reviewed on a periodic basis and dynamically allocated where needed to ensure project success. The Lockheed Management Student Guide (1998, p. 33) states, "Risk management efforts that fail do so because the risk control actions did not keep up with a changing program situation."

As discussed in the previous section, we use risk DTs to model the evolution of the potential RRAs. For example, Figure 3 depicts the Risk #1 risk curves at the start of implementation of the "Prototype" RRA and after the successful demonstration of the prototype. The latter risk curve moves to the left of the original risk curve and is narrower, which reflects a reduced risk. These two risk curves represent the value of the unmitigated risk exposure at two different points in time and, thereby, provide a metric for the risk exposure characteristics. This information is essential if analysts are to track the value of the residual exposure versus the value or cost of the expended RRAs and modify the RRAs as needed to ensure mission success. Note that if the risk curve moves to the right of the original risk curve, it means that risk exposure is increasing, and RRAs need to be re-evaluated.
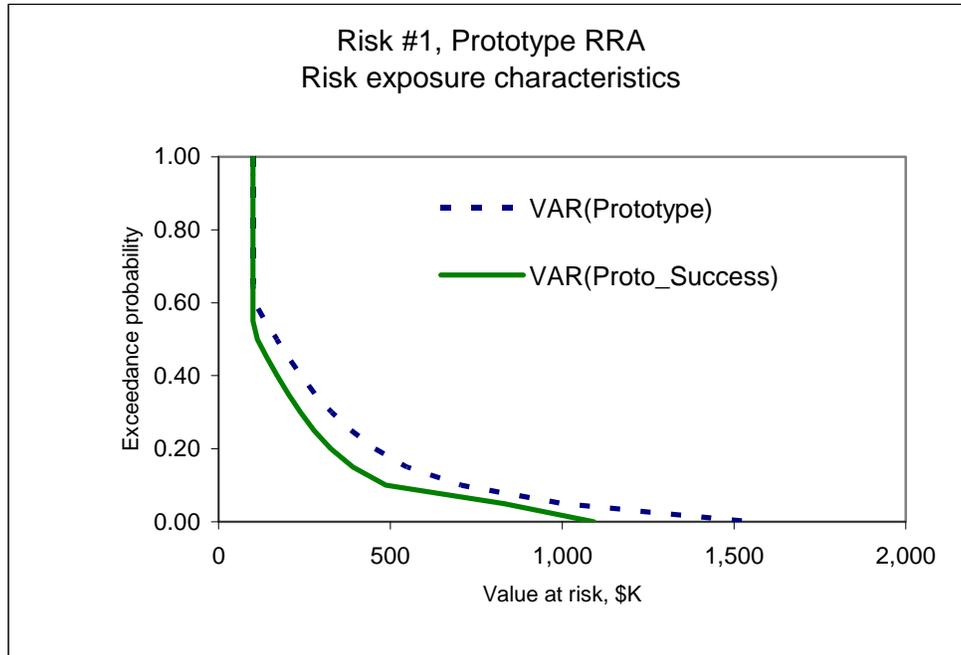
Figure 3. Risk Exposure Characteristics for Risk #1 with Development of a Prototype for Risk Mitigation at the Start and after Successful Demonstration

Application to a Project with Multiple Risks

Now consider the hypothetical project with the following three independent risks: Risk #1 depicted in Figure 1; Risks #2 and #3 depicted in Figure 4a and 4b, respectively. It is both rich and simple enough to illustrate: (1) several diverse RRAs and their analysis, (2) the dynamic nature of the risk picture, and (3) the monitoring of individual risks and allocation of management reserves. The approach readily extends to dependent risks using different probability and outcome values that reflect causality effects among the risks.

Figure 4a may be thought of as the prime contractor subcontracting the engineering and fabrication of a complex module. The prime is considering the following two options: (1) subcontract to a single contractor A, denoted by the branch PDR_A associated with the initial node; (2) carrying two subcontractors and selecting the best one for fabrication at the Preliminary Design Review (PDR). The labeling is somewhat cumbersome because each branch needs to be uniquely identified. The PDR_A sequence represents the decision to proceed with a single contractor. The PDR_AB sequence represents the decision to proceed with two contractors and, at PDR, to select the best one for manufacturing. By selecting two different contractors with different offerings, the prime significantly reduces the probability of PDR failure. RW represents the cost associated with rework; it is modeled with a three-parameter Weibull distribution specified in terms of the 90th, 50th, and 10th percentiles provided by SMEs or historical data.

Figure 4b may be thought of a prime contractor who considers two different Verification and Validation (V&V) strategies as a means for risk reduction. The branch VVS_1_(Start or CDR) represents the use of the standard approach with planned expenditures of $300K. The branch VVS_2_ (Start or CDR) represents the use of a more thorough V&V strategy with greater use of simulation and planned expenditure of $1,000K. The branch RW_1_(PDR or

CDR) represents the rework following the PDR and CDR, respectively. The rework is assumed to be inversely related to the V&V effort, and it is modeled with a three-parameter Weibull distribution specified in terms of the 90th, 50th, and 10th percentiles provided by SMEs or historical data.
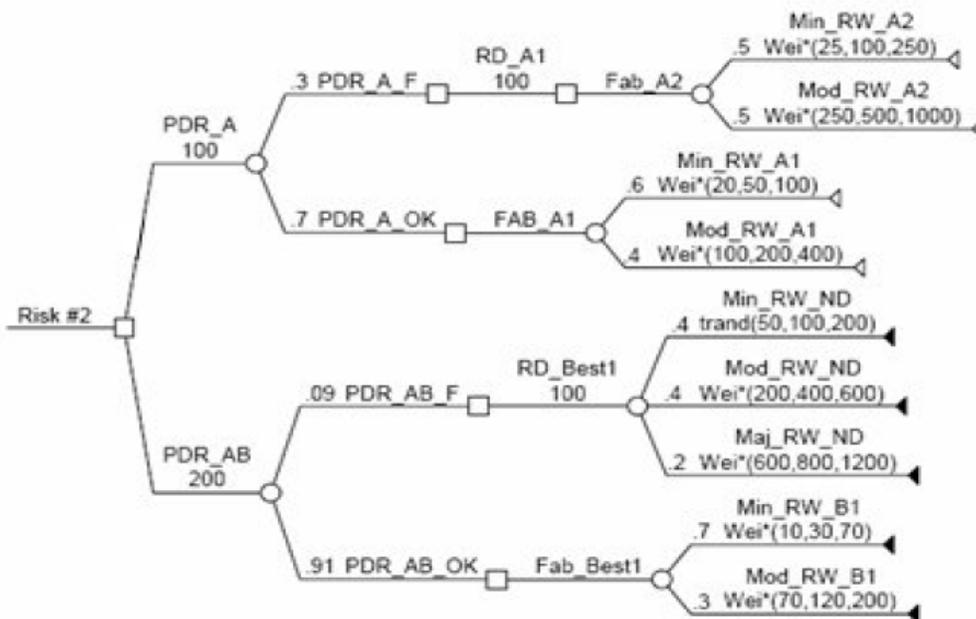

Figure 4a. Generalized Decision Tree for Risk #2 and Two Initial Candidate Risk Response Actions
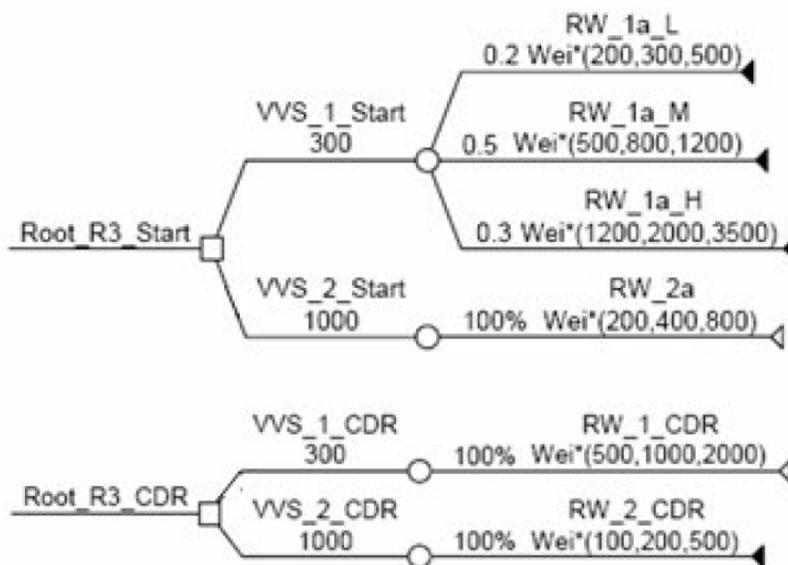
Note: The start (or PDR) and CDR periods are shown separately to simplify the representation of the sequence of events.

Figure 4b. Generalized Decision Tree for Risk #3 and Two Initial Candidate Risk Response Actions

Given the above illustrative project—with three risks each with two potential RRAs—there are eight possible initial Total Project RRAs (TPRRA). As previously discussed, the risk picture is dynamic and gets quite complex as through time. Consider Risk #1 with development of a prototype as a risk reduction option. The prototype may fail or succeed, and the fabrication of the final module may fail or succeed. The full representation of the set of all possible outcomes for even this project is overwhelming and beyond the scope of a symposium paper. We, therefore, limit ourselves to reporting an interesting subset of the complete analysis as follows:

1. We consider only two of the eight TPRRAS.

   a. Strategy 1. Use of the lowest cost-mitigation option for each risk, which is equivalent to proceeding as normal—i.e., no specific RRA for any of the three risks. This is the approach that a risk-seeker project manager would favor.

   b. Strategy 2. Use the most effective RRA for each risk. This corresponds to: (1) developing a prototype for Risk #1, (2) proceeding with two contractors for Risk #2, and (3) implementing a more thorough V&V effort for Risk #3. This is the approach that a risk-averse project manager would favor.

2. For each strategy, we assume the best possible outcomes for the probabilistic nodes through time T1: the Risk #1 prototype and the Risk #2 review PDR_AB succeed. Risk #3 has no gates; the risk reduction is directly accounted in the magnitude of the rework. Figure 5 compares the initial and residual risks under the two strategies.

3. For each strategy, we assume the worst outcomes for the probabilistic nodes through time T1: the Risk #1 prototype and the Risk #2 review PDR_AB fail. Risk #3 has no gates; the risk reduction is directly accounted in the magnitude of the rework. Figure 6 compares the initial and residual risks under the two strategies.

4. For convenience, we also report the 50th, 80th, and mean values for the aggregated risks and individuals risks for strategies 1 and 2 in Tables 1 and 2, respectively.

Useful Information about Risk

We now make a few brief observations. By plotting the risk curves over time for each strategy, we can see from Figure 5 that if the best outcome is realized, both strategies reduce risk (as seen by the T1 curves moving left and becoming more vertical than the start curves over most of the range of analysis). Likewise, we see that if the worst outcome prevails as shown in Figure 6, then both strategies actually increase the cost risk exposure of the project. Graphing risk curves over time thus provides a metric to measure the success of risk mitigation efforts.
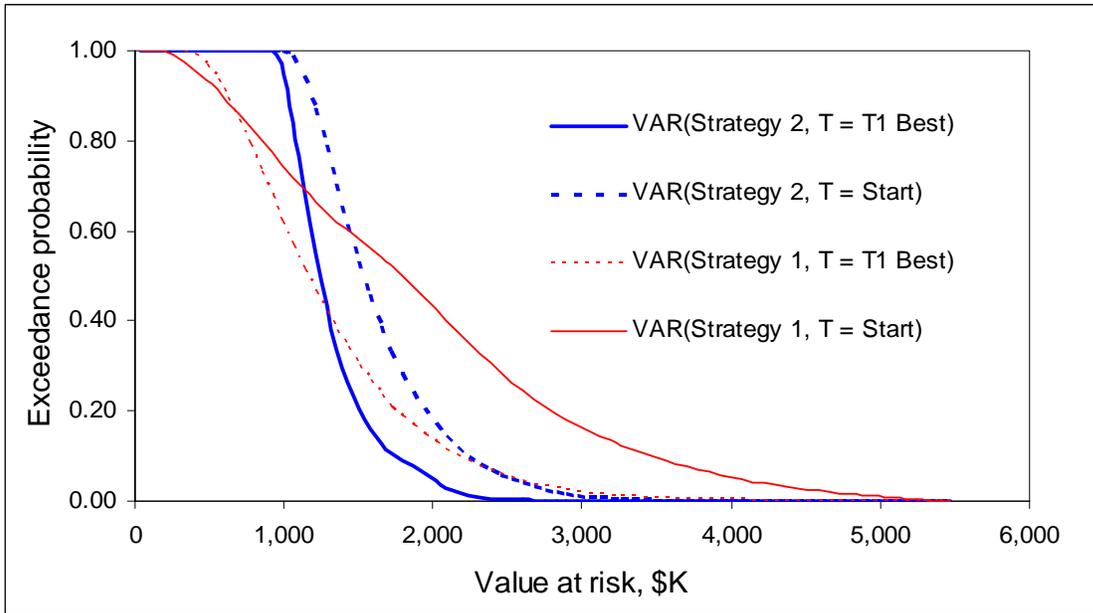
Figure 5. Risk Exposure Characteristics for a Risk-seeking Strategy (Strategy 1) and a Risk-averse Strategy (Strategy 2), Assuming Good Luck Prevails on the Project
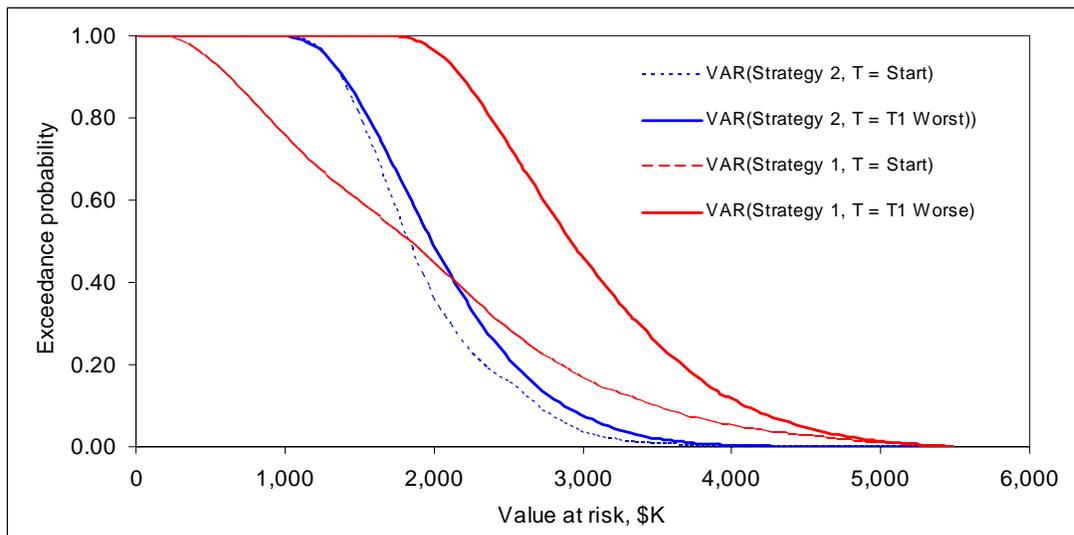

Figure 6. Risk Exposure Characteristics for a Risk-seeking Strategy (Strategy 1) and a Risk-averse Strategy (Strategy 2), Assuming Murphy's Law Prevails on the Project

But the graphs provide even more information. They allow us to consider the risk mitigation qualities of each strategy and to quantify our risk exposure. This information can be used to choose between the two strategies. Note that under the best-case scenario (Figure 5), at the start of the project, Strategy 1 offers a lower risk exposure below $1,500K, while Strategy 2 offers a lower risk exposure above that value. Both strategies are equal in terms of exceedence probability (60 %) at the "breakeven" point of $1,500K. What do we gain by extending the analysis to time T1? We see that the "breakeven" point is lower ($1,200K), and the risk at that point is also lower (40%). So, which one is the best choice? If we were optimists

and certain that the best outcome would be realized, we could make a choice based on the expected benefits. As long as the expected benefits of the RRA are greater than $1,200, we would choose Strategy 2. But of course, we have no such assurance, so let's examine the worst-case scenario.

Figure 6 shows the results of implementing each strategy over time assuming the worst outcome (Murphy's Law). As expected, the risk-seeking Strategy 1 significantly increases our cost risk exposure when things go bad, but the more conservative Strategy 2 is much less sensitive to bad outcomes. In fact, at T1, Strategy 2 dominates Strategy 1— meaning it has a lower risk for any value. If we were pessimists, our choice would be simple: Strategy 2 is especially effective in providing insurance against the worst outcomes.

Which strategy is chosen depends on the decision-maker's risk aversion. Is he/she an optimist or a pessimist? In either case, if the expected benefits of risk mitigation exceed $1,200K, Strategy 2 is the best choice. We believe examining risk information in this way provides useful insight and helps project managers make better choices.

Table 1. Strategy 1 Risk Characteristics at Start and at T1, Assuming that Murphy's Law Prevails on the Project

Strategy #1 - Start

Value at risk, $K

	Risk #1	Risk #2	Risk #3	Composite risk
■ 80th percentile	1388	343	1687	2868
■ Mean	620	222	1148	1990
□ 50th percentile	150	134	878	1850

Strategy #1 - T1 (Worst outcome)

Value at risk, $K

	Risk #1	Risk #2	Risk #3	Composite risk
■ 80th percentile	1575	671	1599	3692
■ Mean	1491	443	1149	3083
□ 50th percentile	1398	344	1000	2945
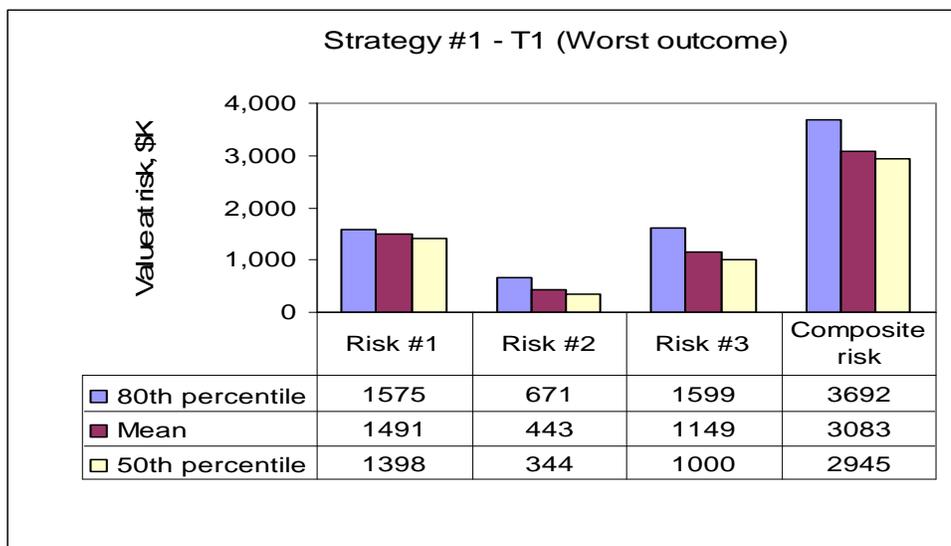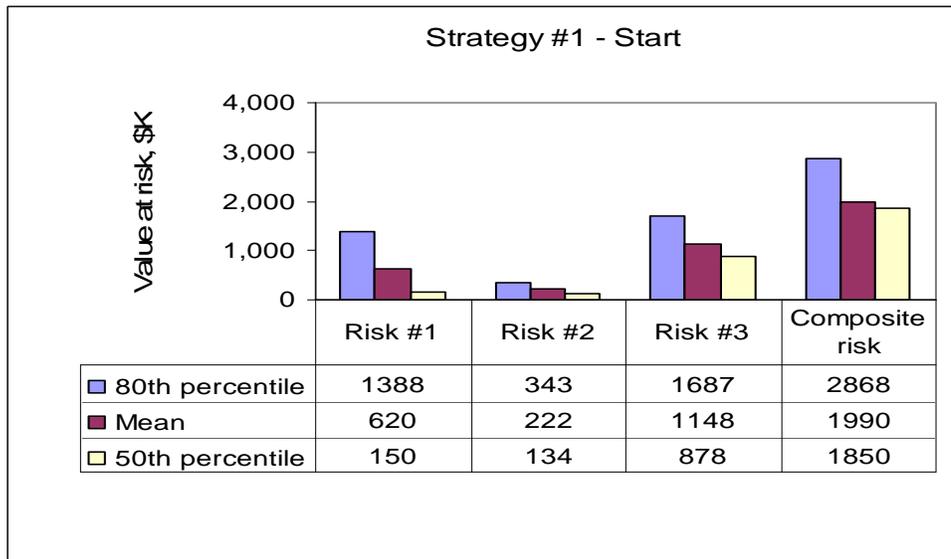
Table 2. Strategy 2 Risk Characteristics at Start and at T1, Assuming that Murphy's Law Prevails on the Project

Strategy #2 - Start

Value at risk, $K

	Risk #1	Risk #2	Risk #3	Composite risk
■ 80th percentile	457	230	1340	2329
■ Mean	305	207	1160	1672
□ 50th percentile	171	152	1100	1846

Strategy #2 - T1 (Worst outcome)

Value at risk, $K

	Risk #1	Risk #2	Risk #3	Composite risk
■ 80th percentile	825	868	1068	2589
■ Mean	588	553	960	2101
□ 50th percentile	490	456	900	2015
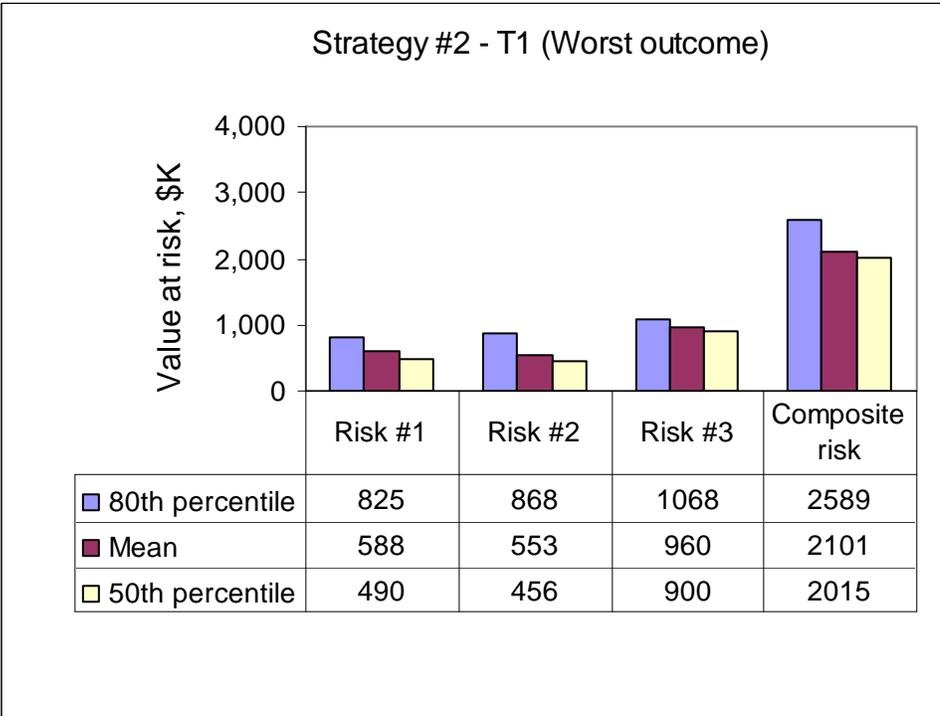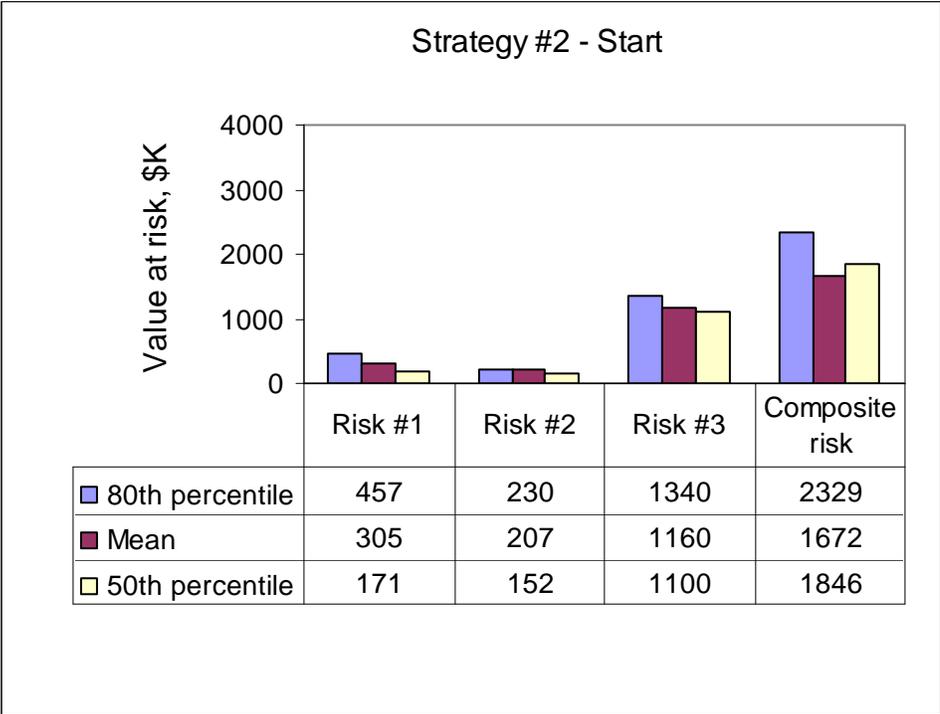
Tables 1 and 2 suggest that the use of mean values is not necessarily a cautious approach for planning project contingency.

Conclusions

We have presented a method for evaluating and tracking project-specific risks at the microscopic level. This type of analysis, as opposed to the macroscopic-level risk analysis, is essential for risk management. While the macro level provides some information about total cost risk, the micro level allows the project manager to plan and control risk response actions that influence total cost risk.

We demonstrated the use of risk decision trees to model the evolution of the potential RRAs, and we used risk curves to evaluate the risk. We believe risk curves are better than the expected-value results usually given by traditional DT analysis because they contain all the risk information both in terms of probabilities and value at risk. This thorough approach allows management to consider what they mean by "acceptable" risk and explicitly models the tradeoff between risk and benefits of any given RRA.

We recommend the use of risk curves to evaluate the performance of RRA and to track their performance over time. If the RRA is working (at reducing risk), we should see the corresponding risk curve move to the left and/or become more vertical. This tracking over time is key to understanding the dynamic nature of risk management and can reveal necessary changes in strategy.

Risk curves derived from Monte Carlo simulation on DTs are particularly useful when analysts are comparing different risk-mitigation strategies. The "breakeven" points help the risk manager understand the conditions under which each strategy is most appropriate. Combined with scenario analysis, it offers an opportunity to make cost-benefit tradeoffs among strategies.

We think that these results provide the detailed information that program managers need and want when they face hard decisions on programs. There is a cost for this type of analysis, but it is small considering the potential benefits. The proposed approach is both practical and mathematically valid and can be implemented using commercially available tools such as Crystal Ball and @Risk. The challenge is to start implementing these more refined cost models and risk management practices.

List of References

Arena, M.V., Blickstein, I., Younossi, O., & Grammich, C.A. (2006). *Why has the cost of Navy ships risen?* Report prepared for US Navy. Santa Monica, CA: RAND.

Arena, M.V., Leonard, R.S., Murray, S.E., & Younossi, O. (2006). *Historical cost growth of completed weapon system programs*. Report prepared for US Air Force. Santa Monica, CA: RAND.

Burgess, R.B. (2007, July). Clout: Navy takes steps to gain better control of acquisition process. *Seapower, 40-44.* Retrieved April 22, 2008, from http://www.seapower-digital.com/seapower/200707/?pg=46

Hollmann, J.K. (2007). The Monte-Carlo challenge: A better approach. In *Proceedings of 2007 AACE International Transactions* (Risk .03.01-03.07). Morgantown, WV: AACE.

Kujawski, E. (2002). Selection of technical risk responses for efficient contingencies. *Systems Engineering, 5*(3), 194-212.

Kujawski, E., & Miller, G.A. (2007). Quantitative risk-based analysis for military counterterrorism systems. *Systems Engineering, 10*(4), 273-289.

OUSD(AT&L). (2006, August). Systems and software engineering, enterprise development. *Risk management guide for DoD acquisition* (6th ed). (Ver. 1.0). Retrieved April 12, 2008, from https://acc.dau.mil/CommunityBrowser.aspx?id=108201

Pennock, M.J., & Haimes, Y.Y. (2002). Principles and guidelines for project risk management. *Systems Engineering*, *5*(2), 89-108.

2003 - 2008 Sponsored Research Topics

Acquisition Management

- Software Requirements for OA
- Managing Services Supply Chain
- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Portfolio Optimization via KVA + RO
- MOSA Contracting Implications
- Strategy for Defense Acquisition Research
- Spiral Development
- BCA: Contractor vs. Organic Growth

Contract Management

- USAF IT Commodity Council
- Contractors in 21st Century Combat Zone
- Joint Contingency Contracting
- Navy Contract Writing Guide
- Commodity Sourcing Strategies
- Past Performance in Source Selection
- USMC Contingency Contracting
- Transforming DoD Contract Closeout
- Model for Optimizing Contingency Contracting Planning and Execution

Financial Management

- PPPs and Government Financing
- Energy Saving Contracts/DoD Mobile Assets
- Capital Budgeting for DoD
- Financing DoD Budget via PPPs
- ROI of Information Warfare Systems
- Acquisitions via leasing: MPS case
- Special Termination Liability in MDAPs

Human Resources

- Learning Management Systems
- Tuition Assistance
- Retention
- Indefinite Reenlistment
- Individual Augmentation

Logistics Management

- R-TOC Aegis Microwave Power Tubes
- Privatization-NOSL/NAWCI
- Army LOG MOD
- PBL (4)
- Contractors Supporting Military Operations
- RFID (4)
- Strategic Sourcing
- ASDS Product Support Analysis
- Analysis of LAV Depot Maintenance
- Diffusion/Variability on Vendor Performance Evaluation
- Optimizing CIWS Lifecycle Support (LCS)

Program Management

- Building Collaborative Capacity
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to Aegis and SSDS
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Terminating Your Own Program
- Collaborative IT Tools Leveraging Competence

A complete listing and electronic copies of published research are available on our website: www.acquisitionresearch.org

Dynamic cost risk assessment for controlling the cost of naval vessels

Edouard Kujawski, Associate Professor, Systems Engineering Department
Diana Angelis, Associate Professor, Defense Research Management Institute
Jeffrey Kline, Senior Lecturer, Operations Research Department
Naval Postgraduate School
Monterey, California

Cost risk analysis à la Dilbert

Cost-overrun problem: Déjà-vu

> *"Their judgment was based more on wishful thinking than on sound calculations of probabilities."*
>
> Thucydides, 431 B.C.E.

➢ Thucydides' observation is very insightful and still appropriate today

☞ Significant problems in cost estimates (2006 RAND study)
  - Systematic bias toward underestimating weapon systems
  - Substantial uncertainty in cost estimates

☞ Congress has concerns about shipbuilding estimates

  NavyTimes, March 20, 2008, " Analyst: Lawmakers do not trust Navy numbers"

The use of Probabilistic Cost Analysis (PCA)

➤ Major shift in R&D and complex projects from deterministic to probabilistic cost analysis
  ▪ Proper framework for handling cost uncertainties
    – Systemic problems
    – Project specific risks

➤ DoD recognizes that uncertainty or risk is an important aspect of cost analysis
  ▪ NAVSEA 05C implements PCA in the Planning, Programmatic, Budgeting, and Execution System

➤ Dr. Etter, Former Assistant Secretary of the Navy for Research, Development, and Acquisition

"Program managers not only need to know a realistic cost estimate for their program, they need to know the percent probability of achieving that target."

Representative probabilistic cost analysis
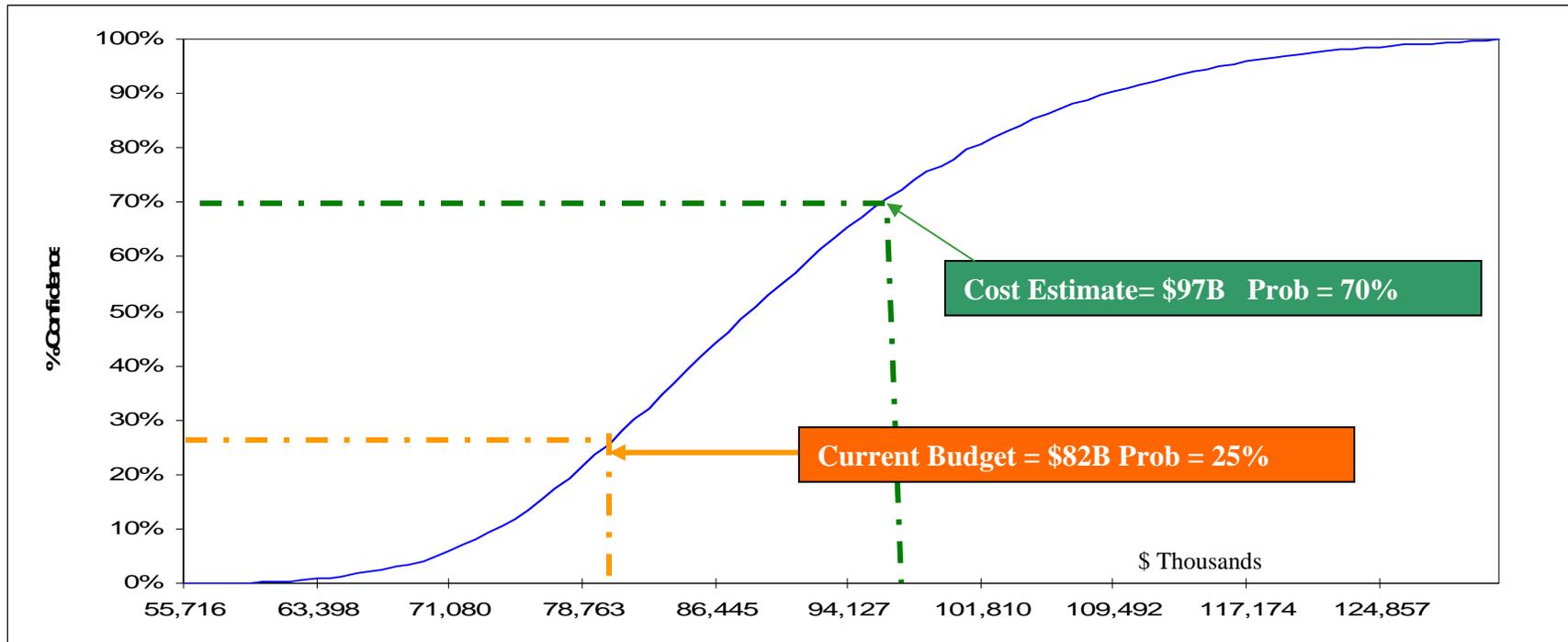
> How much risk are the stakeholders willing to accept?
> Choosing cost point requires understanding consequences.

BUT is today's PCA the silver bullet that slays the cost overrun problem?

Budget allocation impacts project cost and probability of success
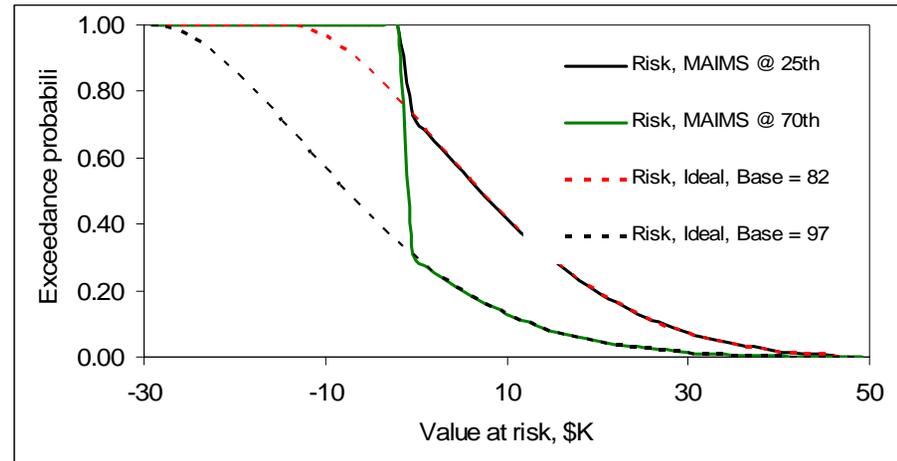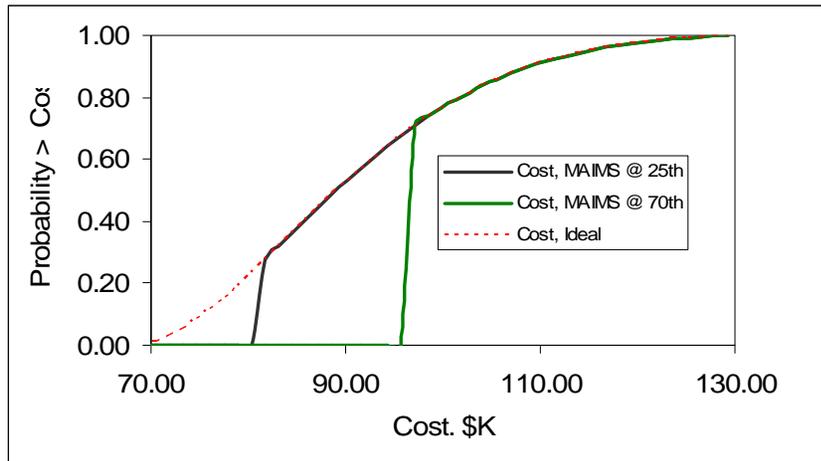
Mythical Projects

- "100% Rational" project team
- Each project spends only as necessary to satisfy requirements
- Actual cost may be less than budgeted costs

Real Projects

- Human & organizational influences
- MAIMS principle: "Money Allocated Is Money Spent"
- Actual cost increases with higher allocated budget

➤ *High cost NEED NOT provide high probability of success.*
➤ Choosing cost point requires understanding consequences.
➤ Today's typical PCA relies on expected values and underestimates cost.

Probabilistic cost analysis
A physician metaphor

Mrs. Jones, the test shows that your current blood cholesterol level and weight are much higher than the normal levels; also given that you have been smoking in the past 20 years, I believe that you are vulnerable to a heart attack.

Oh?!

So, see you next year. **Good Bye**.

Risk Assessment Triplet Questions [Kaplan and Garrick, 1981]:

- "What can go wrong?"
- "What is the likelihood?"
- "What are the consequences?"
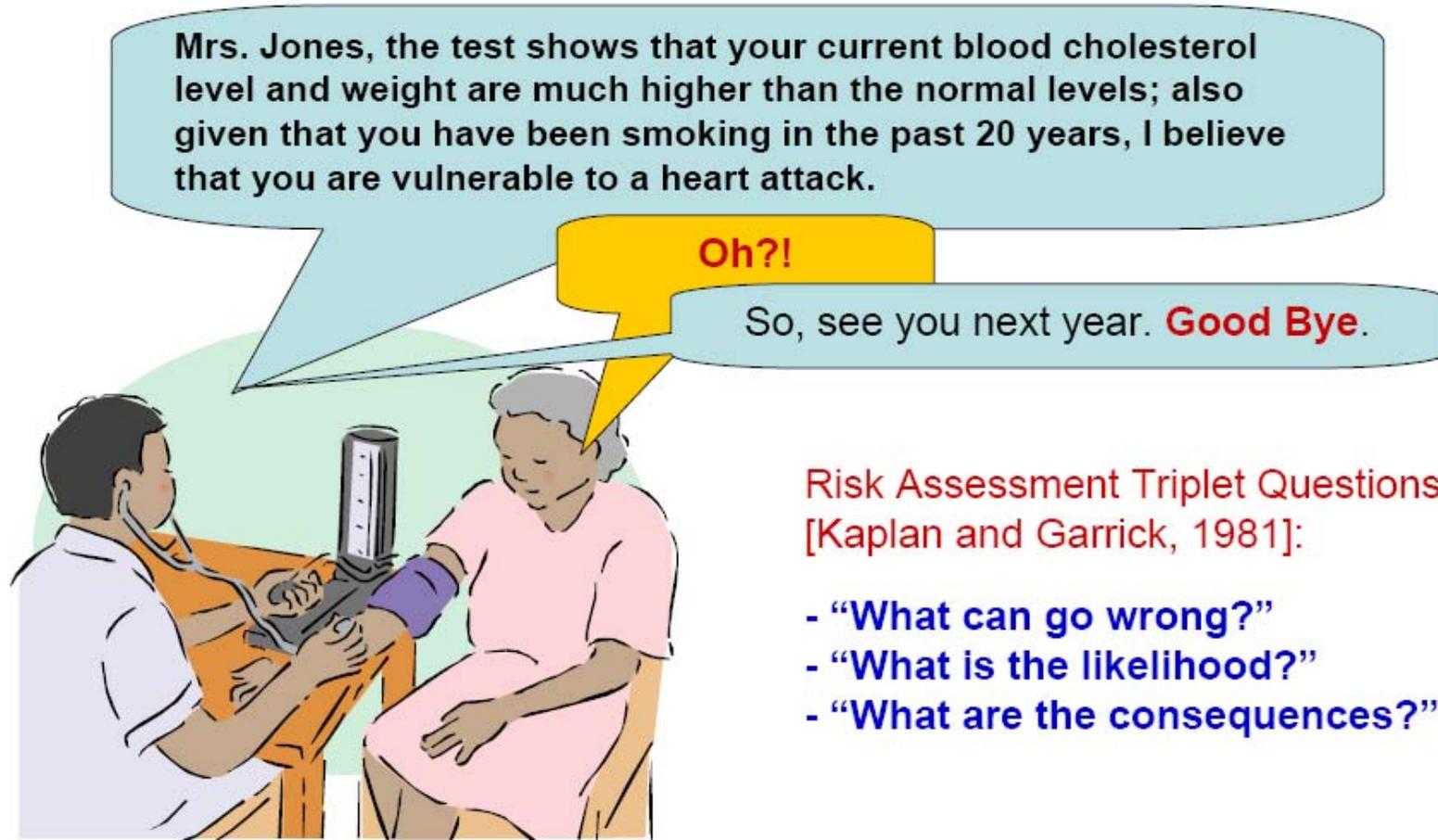
Adapted from Yacov Y. Haimes, NPS 2007

Dynamic cost risk management
A physician metaphor

Mrs. Jones, I think you should quit smoking, exercise, and follow a healthy diet. Alternatively, I can prescribe some medications for you now, which can help bring down your blood cholesterol level more quickly, but there might be some side effects. My recommendation is to do both.

So, what shall I do?

Risk Management Triplet Questions [Haimes, 1991]:

- "What can be done and what options are available?"
- "What are the tradeoffs in terms of all costs, benefits, and risks?"
- "What are the impacts of current decisions on future options?"

Adapted from Yacov Y. Haimes, NPS 2007

Sources of cost uncertainty

Macroscopic analysis

- Economic, Materials & Labor, Learning rates

- Effectively modeled using classical PDFs
  - Triangular, Beta, Lognormal, Weibull distributions, …

- ☹ But these only constitute a fraction of today's typical project risk drivers

Microscopic analysis

- Project-specific, high consequence risks
  - Technology, Design, Change orders,…

- Need to be analyzed within the framework of a complete risk management effort

- Modeling and analysis tools
  - Decision trees, influence diagrams
  - Monte-Carlo simulation

Integrate PCA into the DoD risk management process

Risk Identification

Project Risk Costs

Risk Mitigation Costs

Risk Tracking

Risk Analysis

Risk Registry

Risk Mitigation Planning

Risk Mitigation Plan Implementation

Risk Mitigation Plans/Status

Extended PCA
Dynamic cost risk management

- Identify project-specific risks

- Screen for further analysis and mitigation

- Develop risk response actions

- Model risk and actions using decision tree

- Model cost uncertainty with continuous and discrete distributions

- Use simulation to explore value of risk response actions

Total Project Cost = Baseline Cost + Risk Costs

Macroscopic baseline costs

Microscopic risk costs

Total Cost =
Macroscopic baseline costs
+ Microscopic risk costs

LIKELIHOOD (PROBABILITY)
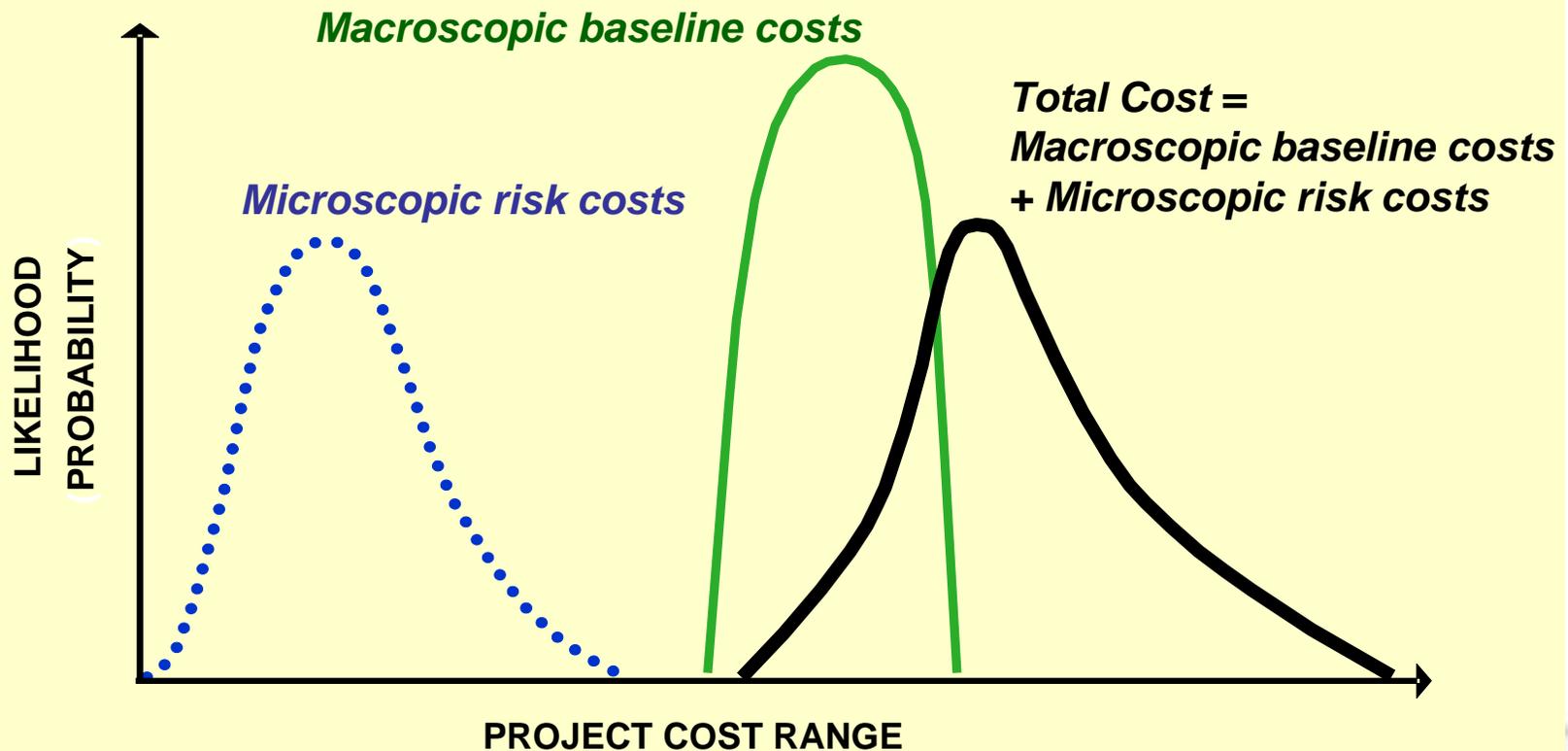
PROJECT COST RANGE

☺ The microscopic view is a powerful risk analysis method
☹ However, it is too cumbersome to individually analyze every risk
☞ It complements and needs to be integrated within the PCA

Project cost and uncertainty over time
A very dynamic picture
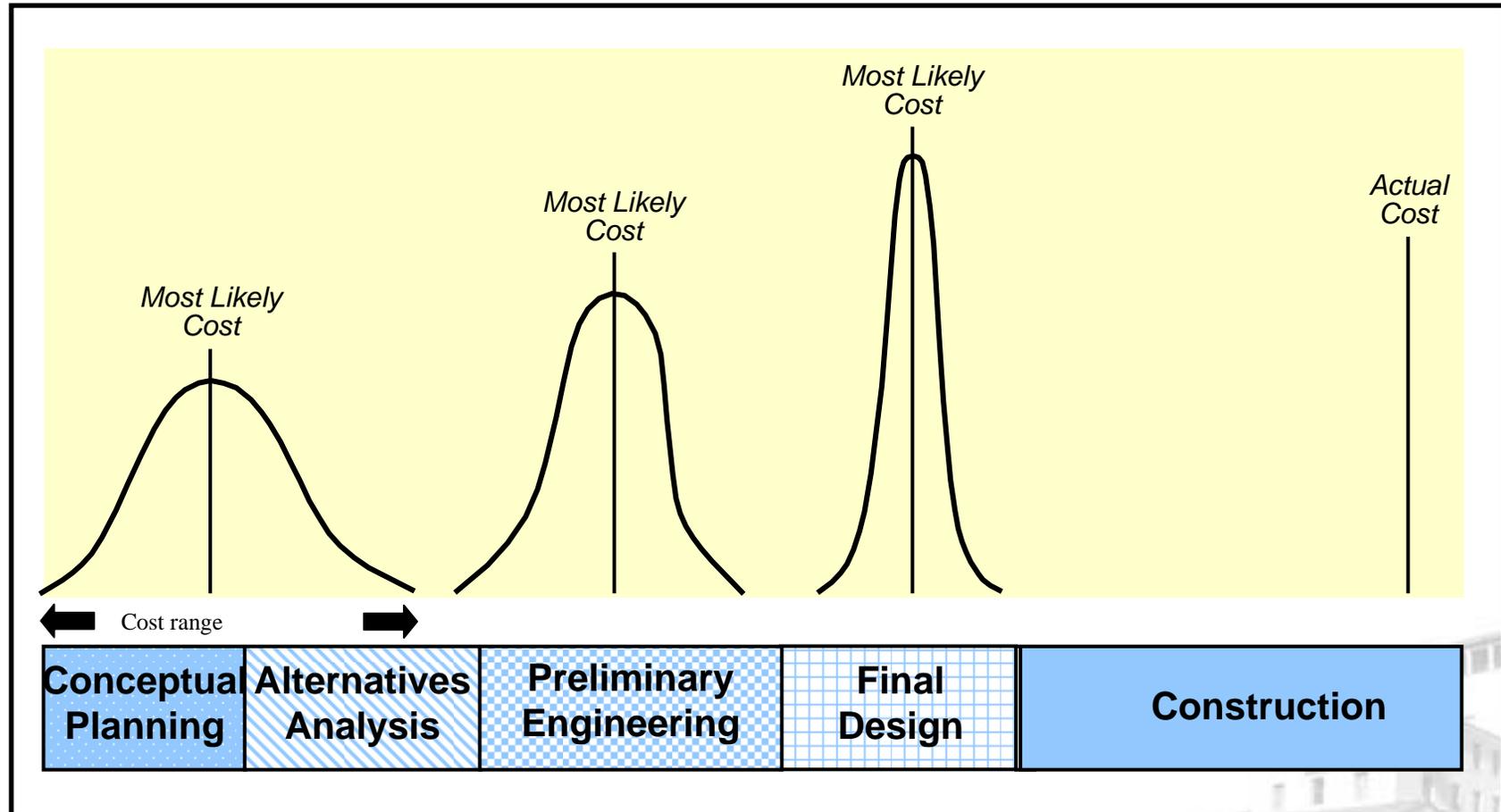
Example #1 – Single risk, Risk #1

Risk #1, RRA: Prototype module

Frequency vs Value at risk, $K

Risk #1, RRA: Fabricate module

Frequency vs Value at risk, $K

Module #1 (T = Start)

Probability(< X) vs Cost, $K
- Cost(Prototype)
- Cost(Fab A2)
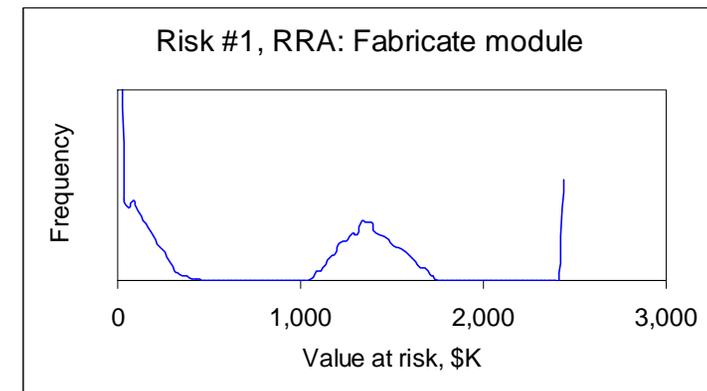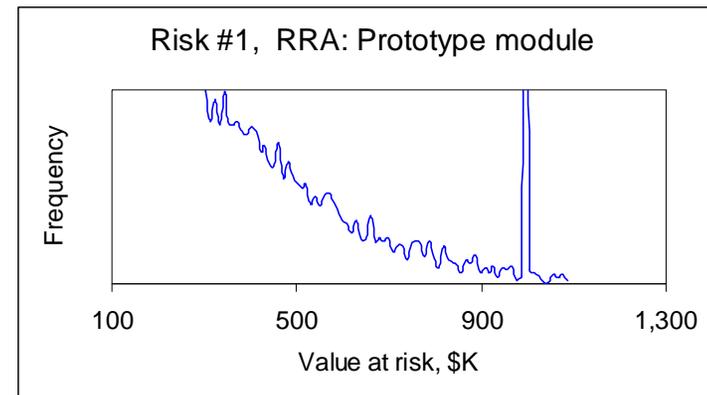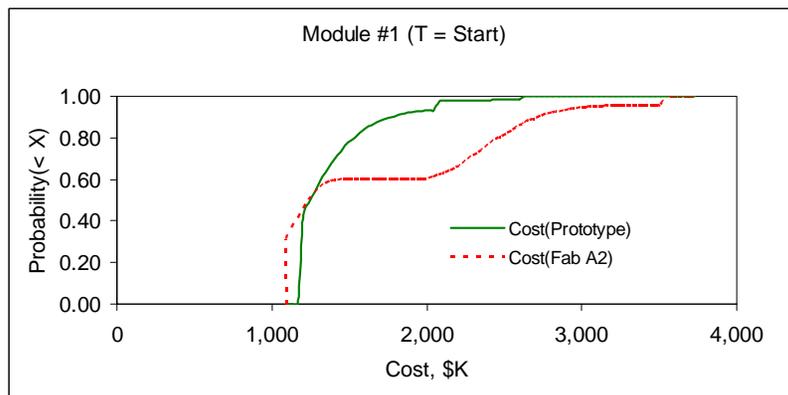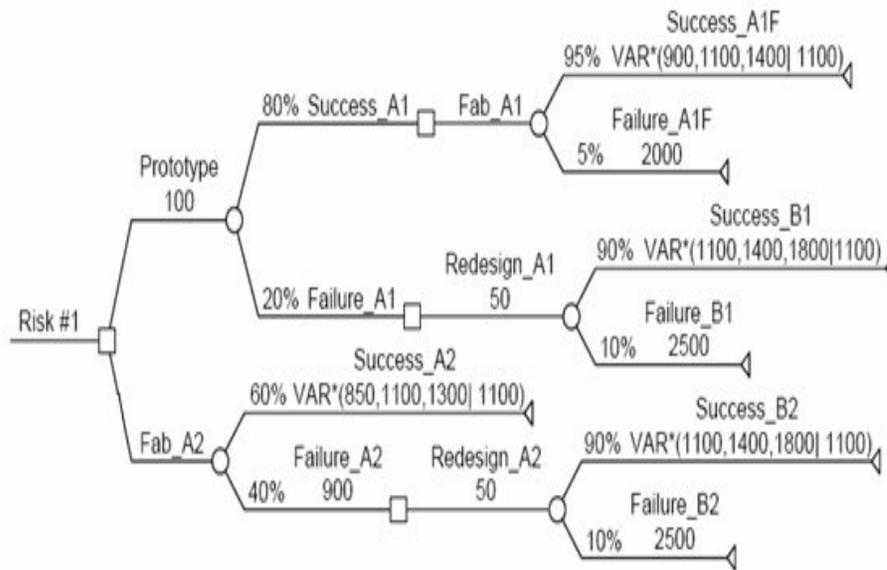
➤ Risk #1 is associated with the fabrication of a complex module
➤ Two RRAs
  – Directly fabricate module
  – Build prototype first

Enhanced Decision Tree Analysis (DTA)

Standard DTA	Enhanced DTA
▪ Information lost in folding back ▪ Decisions based on expected value ▪ Representation quickly becomes too bushy	▪ Spectrum of outcomes explicit ▪ Decisions based on risk profiles and DM's attitude toward risk ▪ Compact representation ▪ Readily implemented using commercially available SW

➢ Enhanced DTA provides more complete and meaningful information than standard DTA for the same data.

Multiple risks

☞ Consider a project/program with m base cost elements {BC_j} and n credible, high-consequence risks and/or opportunities {R_i}

- Each base cost element may be modeled as a point estimate or continuous PDF
- Each risk is characterized by a probability of occurrence pi a spectrum of possible outcomes with a PDF $L_i(x)$

✎ Think of project/program of risks is a risk/opportunity portfolio with a generalized discrete PDF

$$R_S(x) \equiv \left\{ \langle p_1, L_1(x) \rangle, \langle p_2, L_2(x) \rangle, \ldots, \langle p_n, L_n(x) \rangle, \left\langle 1 - \sum_{i=1}^{n} p_i, 0 \right\rangle \right\}$$

✎ The total cost is then the probabilistic sum of the m base cost elements and n risk-driver costs

$$TC(x) = \sum_{i=1}^{m} BC_i(x) \oplus \sum_{i=1}^{n} p_i L_i(x)$$

Example # 2 – Project with 3 risks

Risk #1 – slide 14
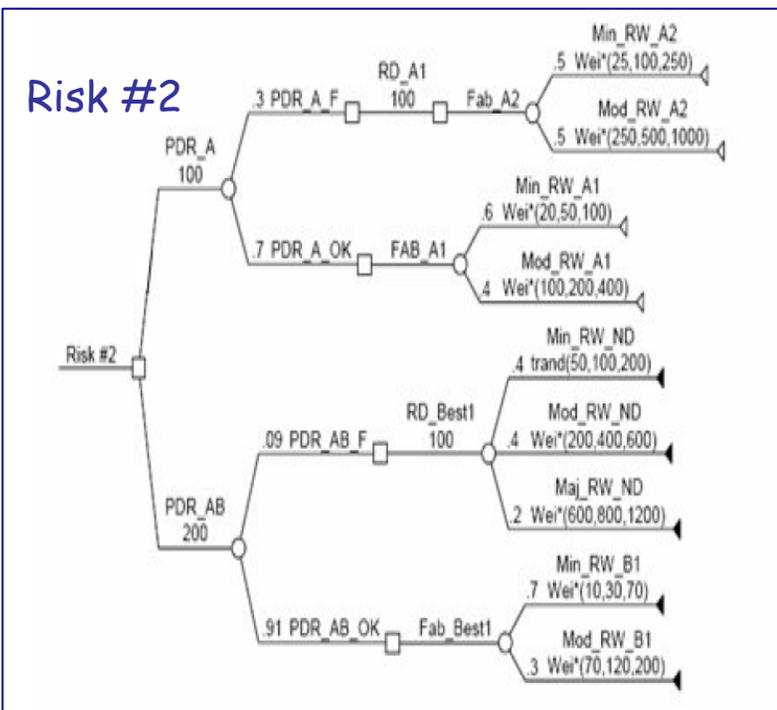
Risk #2

Risk #3

Risk #2: high-risk subcontract
– Single contractor
– Two contractors, downselect at PDR
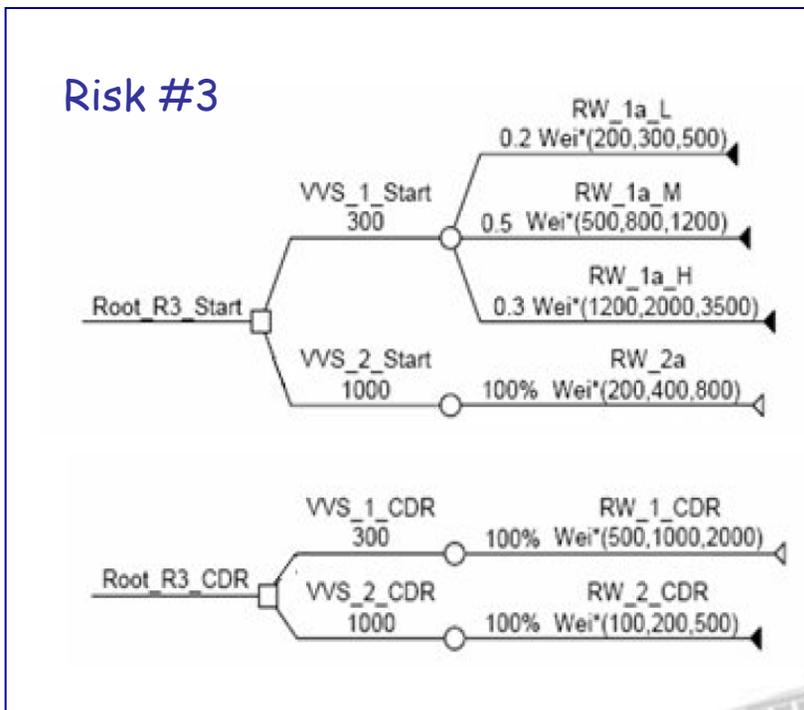
Risk #3: contractor considers two V&V strategies for risk reduction
- Standard V&V
- Extensive modeling and simulation

# Example # 2-Dynamic risk curves
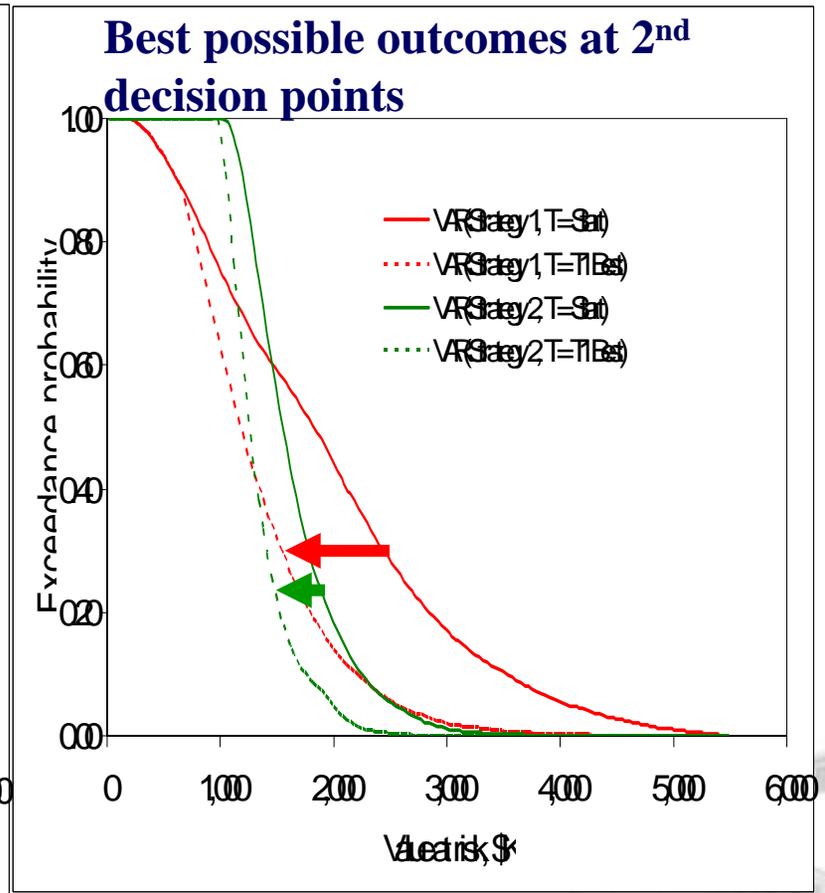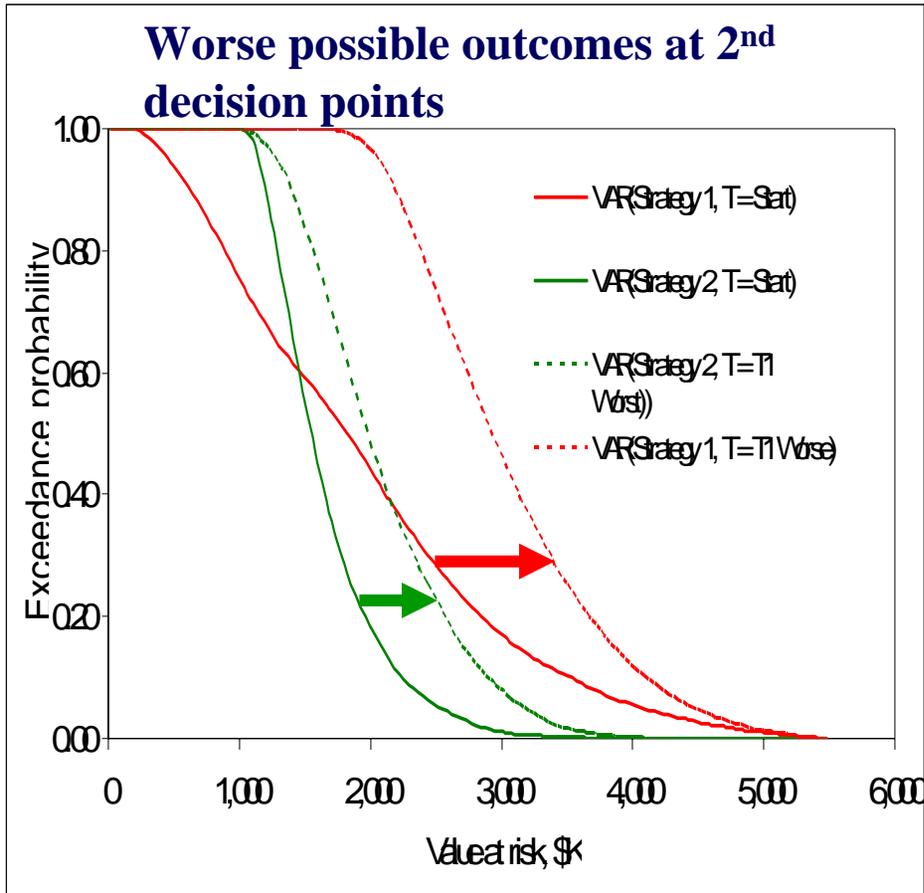
Example # 2 - Range of Risk
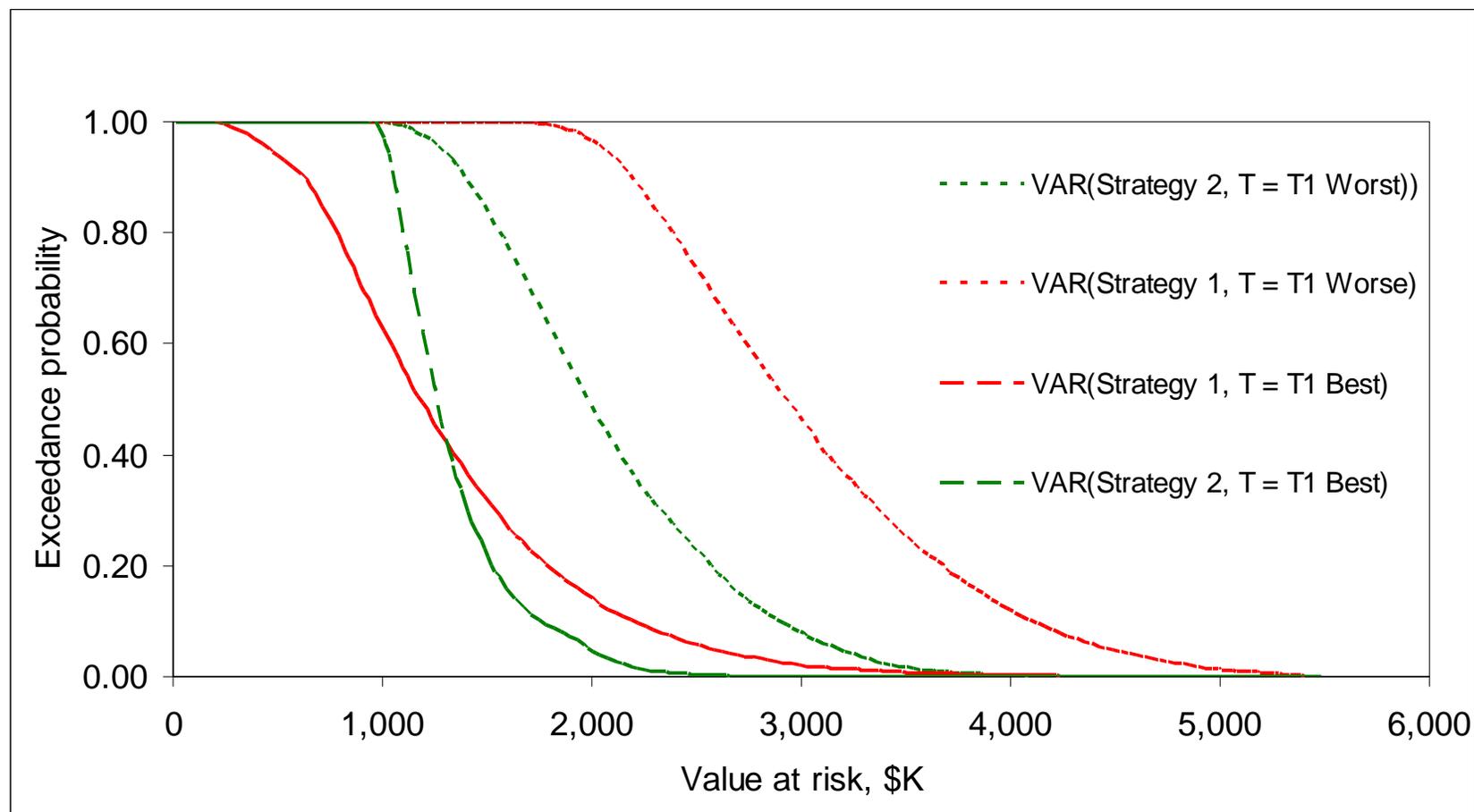
Example #2 - Comparing Strategies
(Best Scenario)
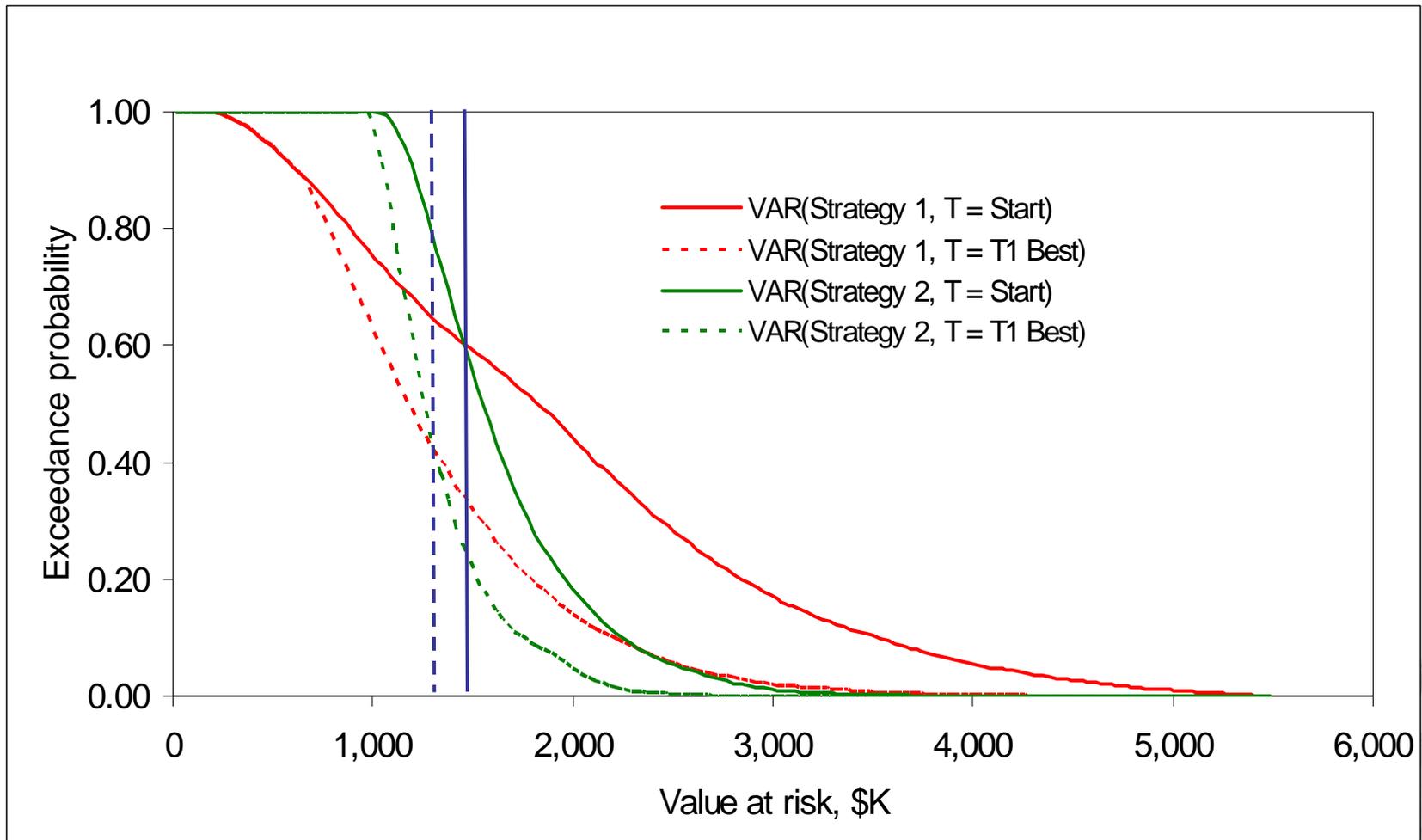
Example #2 - Comparing Strategies
(Worst Scenario)
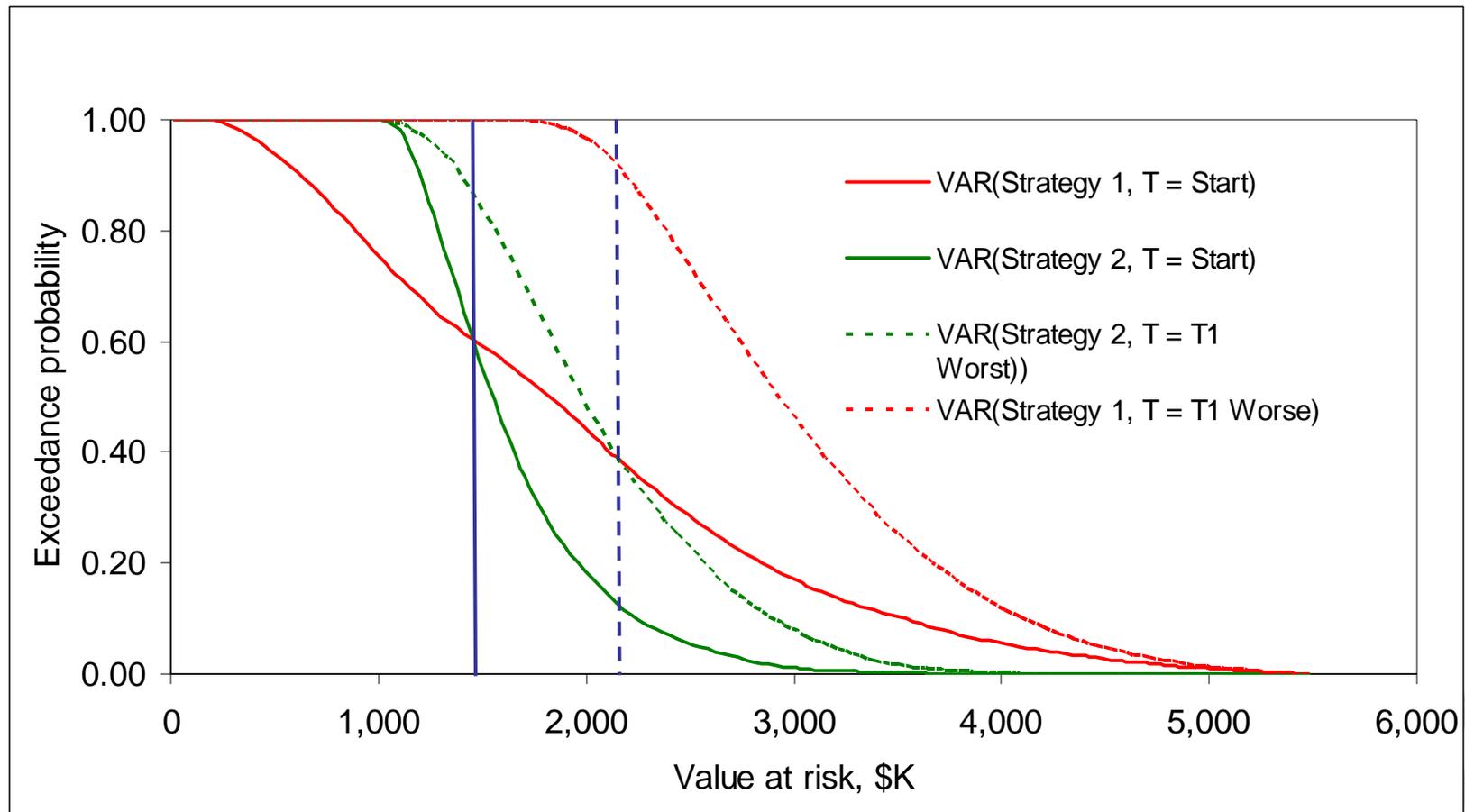
Conclusions

- ➢ Project-specific cost risks can be modeled using decision trees and simulation
  - – Micro level essential for risk management

- ➢ Dynamic risk curve analysis can be used to select and track performance of risk response actions over time
  - – Enable cost-risk tradeoffs

- • Dynamic risk analysis and management are key to improve project/program technical performance, schedule, and cost

Further Research

- ❑ Incorporate multiple risks into dynamic risk analysis and management
  - – Solve for optimal risk mitigation strategy

- ❑ Expand results to budget implications of cost estimates

- ❑ Integrate with schedule and technical performance